Analysis and Control of DFIG Based Wind Turbine in Power System
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Abstract—The main purpose of this paper is to check the stability for DFIG (Doubly Fed Induction Generator) using reduced order model. For power system transient studies inclusion of the network transients and generator stator transients increases the order of the overall system model. Further, a small time step is required for numerical integration resulting in an increased computational time. In this paper reduced order (3rd) machine models are described and the control of the wind turbine discussed. The capability of the DFIG for speed control and its performance during a speed change is also addressed.

Key words: DFIG (Doubly Fed Induction Generator), Machine Models, Wind Turbine

I. INTRODUCTION
In recent year, there has been a widespread growth in the exploitation of wind energy, which required the development of larger and more robust wind energy conversion systems (WECS). The electricity industry worldwide is turning increasingly to renewable sources of energy to generate electricity. Wind is the fastest growing and the most widely utilized emerging renewable energy technology for power generation at present, with a total of approximately 250 GW installed worldwide up to 2012[1].

India ranks fifth amongst the wind energy producing countries of the world after USA, China, Germany and Spain. The installed capacity of wind power in India has reached about 20 GW by 2013. The global electrical energy consumption is rising day by day and there is steady increase of the demand on power generation. So in addition to conventional power generation units a large no. of renewable energy units is being integrated into the power system. A wind electrical generation system is the most cost competitive of all the environmentally clean and safe renewable energy sources in world. Considering various renewable energy sources, wind energy has emerged as the most viable source of electrical power and it is economically competitive with conventional sources [2-3]. The wind energy conversion system (WECS) could be operationally classified into fixed speed and variable speed wind turbine generating system (WTGS). Both fixed-speed induction generator and variable speed double fed induction generator are used in wind turbine generation. [4-5],in fixed speed induction generator the stator phase voltages supplied by the grid are unbalanced, the torque developed in induction generator is not constant. This can result in acoustic noise at low levels and at high levels can damage other parts like rotor shaft, gearbox, or blade assembly. Wind energy has been the subject of much recent research and development.

Now, to overcome the problems related to fixed speed wind turbine system and to maximize the wind energy capture, many new wind farms will employ variable speed wind turbine. DFIG gives several advantages when compared with fixed speed generators including speed control and voltage control. These merits are primarily achieved via control of the rotor side converter. The configurations of variable-speed generation that employ a doubly fed induction generator (DFIG) with a four-quadrant ac-to-ac converter connected to the rotor windings present noticeable advantages such as the decoupled control of active and reactive power of the generator, the improvement of system efficiency, and the fact that the rotor power converter needs only a fraction (25–30%) of the total power to achieve full control of the generator. DFIG’s ability to control rotor currents allows for reactive power control and variable speed operation, so it can operate at maximum efficiency over a wide range of wind speeds[6-7].The complete-order modeling of synchronous and induction machines for wind turbine applications using the state-space representation is shown. The models are presented in a systematic way so that reduced order models can be obtained directly [8-9]. In this Paper a 3rd order machine model is represented where the stator transient are neglected [10].

II. DOUBLY FED INDUCTION GENERATOR (DFIG)
DFIG (Double Fed Induction Generator) is one of the components of Variable speed wind turbine system. DFIG offers several advantages when compared with fixed speed generators. Its stator winding is directly connected to grid and their rotor winding is connected to the grid through an AC/DC/AC converter. AC/DC converter connected to rotor winding is called rotor side converter (RSC) and another DC/AC is grid side converter (GSC). The freq. of ac supply fed to the rotor is calculated using below formula.

\[ fr = \frac{f_{net} \times Np}{120} \]

Where fnet. Is the network frequency and \( N_p \) is the rotor speed. If the speed of the rotor is a synchronous speed then the rotor freq. is zero to be fed. If the speed of the rotor is decrease then the rotor freq. fed into the rotor is a positive polarity. Same if rotor speed increases as compare synch. Speed then fed into a rotor is a negative polarity. This calculation is used to maintain v/f ratio. The below fig. shows the working of DFIG.

Fig. 1: Working of DFIG

DFIG designs, the frequency converter is built by self-commutated PWM converters, a machine-side converter, with an intermediate DC voltage link. Variable speed operation is achieved by injecting a variable voltage
into the rotor at slip frequency. Power converters which allow decoupled control of both active and reactive power.

In normal operation the aim of the rotor side converter is to control independently the active and reactive power on the grid. The grid side converter has to keep the dc-link capacitor voltage at a set value. The control system of a variable speed wind turbine with DFIG has as control the reactive power interchanged between the generator and the grid and the active power drawn from the wind turbine. Rotor current split into two component d and q. The q component regulate torque and d regulate p.f and terminal voltage RSC control which controls active and reactive power on the stator side. GSC control that regulates the DC-link voltage to maintain it constant and can be used to inject additional reactive power to the grid.

III. THIRD ORDER MODEL OF THE DFIG

In power system it has become conventional to reduce the order of the generator and neglect the network transients for stability analysis of large power systems. Different methods of reducing generator equations are discussed in [10]. In this investigation, a standard method of reducing the order of the induction generator model was considered where the rate of change of stator flux linkage is neglected. The reduced order model was derived by ignoring the differential term. Which is equivalent to neglecting the stator electric transients [10].

A. Machine Model Equation

The reduced order voltage equations in pu: Tm is the mechanical torque, dependent upon the local wind speed.

\[
\frac{dw_r}{dt} = \frac{1}{J}(T_m - TR)
\]  

When the stator transient is neglected, the simplified machine equations given by:

\[
v_{ds} = R_s i_{ds} - X_1 i_{qs} + e_d
\]  

\[
v_{qs} = R_s i_{qs} + X_1 i_{ds} + e_q
\]  

\[
\frac{de_{ds}}{dt} = \frac{1}{R_s}[e_d + \frac{L_m}{L_{rr}} i_{qs}] + s \omega_s w_s + e_w - \omega_s \frac{L_m}{L_{rr}} v_{qr}
\]  

\[
\frac{de_{qs}}{dt} = \frac{1}{R_s}[e_q + \frac{L_m}{L_{rr}} i_{ds}] - s \omega_s w_s + e_d - \omega_s \frac{L_m}{L_{rr}} v_{dr}
\]

Where \(T_R = \frac{L_m}{L_{ss}} v_{ds}\)

The electrical torque is given by:

\[
T_e = \frac{1}{L_{rr}} [i_{ds} v_{ds} + i_{qr} v_{qr}]
\]

The rotor voltage equation can also be transformed into the d-q frame, similarly as the stator equations, and the following equation results:

\[
\begin{bmatrix} v_{dr} \\ v_{qr} \end{bmatrix} = R_r \begin{bmatrix} i_{dr} \\ i_{qr} \end{bmatrix} + s \omega_s \begin{bmatrix} \lambda_{qr} \\ \lambda_{dr} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \lambda_{dr} \\ \lambda_{qr} \end{bmatrix}
\]

Similarly the flux equations can be transformed into the d-q frame and the new flux equations are:

\[
\lambda_{dr} = \lambda_{dr} + L_m i_{ds} + L_{rr} i_{qr}
\]

\[
\lambda_{qr} = \lambda_{qr} + L_m i_{qs} + L_{rr} i_{dr}
\]

B. Speed/torque and Voltage Control

Speed control was achieved by driving the machine along an optimum torque speed curve, which corresponds to the maximum power extraction from the wind. Between the cut-in and speed limit, the optimum torque-speed curve was characterized by an optimal characteristic curve given by \(T_{opt} = C_p \omega_w^2\) (where \(\omega_w\) is the measured rotor speed). The set point torque corresponding to the speed of the machine was then translated into the reference of \(i_{qr}\). In order to linearize the controller, \(v_{ds}\) was neglected with respect to \(v_{qr}\).

IV. SIMULATION MODEL

A. Modeling of Wind Turbine

The algebraic relation between wind speed (\(\omega_w\)) and mechanical power extracted (Pm) is described by the following relation:

\[
P_m = 0.5 \rho A V_w^3 C_p(\lambda, \beta)
\]

Where

- \(\rho\) is the air density (Kg/m^3)
- \(C_p\) is the power coefficient
- \(\lambda\) is the tip speed ratio
- \(\beta\) is the pitch angle (deg.)
- \(A\) is the area covered by the rotor (m^2)
- \(P\) is differential operator (p = d/dt)
B. Mathematical Model

Here in mathematical model of machine model and control block which is shown in below model. In this model in wind turbine model value of $\lambda$ is taking 8.1 and value of $\beta$ is taking here is 1 for maximum power extraction. In order to linearize the controller, $v_{sd}$ was neglected with respect to $v_{qs}$.

![Mathematical model](image)

Fig. 6: Mathematical model

V. SIMULATION RESULT

A. Start Up with Zero Rotor Injection

![Start up result with zero rotor injection](image)

Fig. 7: Start up result with zero rotor injection

B. Without Control

![Without control](image)

Fig. 8: Without control due to step change in wind speed

C. With Control

![With control](image)

Fig. 9: With control due to step change in wind speed

Here all three simulation result shows three different condition.

First show the startup condition of the generator and result of rotor speed, Electromagnetic torque and stator current. Second result shows the result of step changes of wind speed (3 to 14) m/s without control. Third result shows the result with control. Here simulation run time is $t = 5$ s.

VI. CONCLUSION

These papers represent the stability analysis of DFIG based wind turbine. In 3rd order model give the similar accurate result with compare detailed 5th order model. Phasor domain electro-mechanical dynamic studies of large power systems give the simplicity and reduced computation time of the 3rd order model is quite attractive in transient stability analysis in power system with reduced equation model; it takes less time for computation.

APPENDIX A: LIST OF SYMBOLS

- $v_s, v_r$ Stator and rotor voltage
- $i_s, i_r$ Stator and rotor current
- $v_a, i_a$ Stator side converter voltage and current
- $P_g, Q_g, v_n$ Generated active and reactive power
- $R_s, R_r$ Stator and rotor machine resistance
- $w_s, w_{base}, w_r$ Synchronous, base and rotor angular frequency
- $\lambda$ Flux linkage
- $L_m$ Mutual inductance between the stator and the rotor
- $L_{ss}, L_{rr}$ Stator and rotor self-inductances Rotor slip
- $X_s, X_r$ Transient or short circuit reactance and Open circuit reactance
- $e_d, e_q$ Voltage behind transient reactance d-q Component
- $T_o, T_{sp}$ Mechanical, electromagnetic, set point Torque
- $T_m$ Mechanical torque

APPENDIX B

$f_s = 50$ Hz, $R_s = 0.0048$, $R_r = 0.00549$, $H = 3.5$, $X_m = 3.9527$, $X_{ls} = 0.09241$, $X_{lr} = 0.09955$, $L_{ss} = (X_m + X_{ls})/2\pi f = 4.0451$, $L_{rr} = 3.9527$, $L_{rr} = 0.09241$, $L_{rs} = 0.09955$, $L_{ss} = (X_m + X_{ls})/2\pi f = 4.0451$, $L_{rr} = 0.09955$. All rights reserved by www.ijsrd.com
\[ L_{rr} = \frac{(X_m + X_{l'})}{2\pi f} = 4.0522 \]

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